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The impact of verbal instructions on goal-directed behaviour

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A B S T R A C T

It is common to use verbal instructions when performing complex tasks. To evaluate how such instructions contribute to cognitive control, mixing costs (as a measure of sustained concentration on task) were evaluated in two task-switching experiments combining the list and alternating runs paradigms. Participants responded to bivalent stimuli according to a characteristic explicitly defined by a visually presented instructional cue. The processing of the cue was conducted under four conditions across the two experiments: Silent Reading, Reading Aloud, Articulatory Suppression, and dual mode (visual and audio) presentation. The type of cue processing produced a substantial impact on the mixing costs, where its magnitude was greatest with articulatory suppression and minimal with reading aloud and dual mode presentations. Interestingly, silently reading the cue only provided medium levels of mixing cost. The experiments demonstrate that relevant verbal instructions boost sustained concentration on task goals when maintaining multiple tasks.

1. Introduction

When working towards a task of some complexity it is not uncommon to verbalise our intentions, in a form of self-direction, or self-instruction (Vygotski, 1962). Consider assembling a piece of furniture; in addition to following the prescribed instructions, we may often find ourselves stating aloud the process of assembly — "attach piece A to piece B with bolt C", for example. Why these vocalisations are used, or if they provide any benefit, is uncertain; particularly when it is a commonly held belief that best performance in a task is found when it is fulfilled in silence — 'to give the task our full attention'. Therefore, the issue remains of whether vocalising instructions permits a greater level of cognitive control.

The theory of a central executive for working memory has been widely used to explain behaviour in this context (Baddeley, 1986; Baddeley & Hitch, 1974). One of its components, the sub-vocal rehearsal loop, provides assistance in sustaining verbal information in working memory to be used in subsequent actions (Baddeley & Wilson, 1985; Gathercole & Baddeley, 1993). To understand its functioning, consider having to memorise a phone number. To do so exclusively on its visual information can be very challenging and it is likely that one would perform outer or inner-speech recitals of the number to enhance the likelihood of 'committing it to memory' (Levy, 1971). Not only does the sub-vocal rehearsal loop perform this task, but it also translates non-speech and non-auditory materials (such as on-screen text, for example) into an internalised verbal form; this can then be held in working memory for later use (Gathercole & Baddeley, 1993).

The degree to which inner-speech is used cannot, by the nature of it, be measured; it is internal. Discussions with participants have previously highlighted their use of it in silent tasks (Emerson & Miyake, 2003), but its potential role has also been investigated by implementing disruption tactics. If participants engage in inner-speech when completing a task in silence, then performing an irrelevant concurrent articulation would theoretically interfere with performance. In support of this, it has been found that when irrelevant secondary articulations are performed, task competency deteriorates. This strategy is known as Articulatory Suppression, and it has been applied in the form of repetitions of irrelevant syllables (Saeki & Saito, 2004), numbers (Baddeley, Lewis, & Vallar, 1984), words (Baddeley, Chincotta, & Adlam, 2001; Bryck & Mayr, 2005), and letters (Emerson & Miyake, 2003).

When a participant is asked to perform irrelevant vocalisations during paradigms involving two or more tasks, their performance is badly affected, in the form of larger reaction times (RT) and/or an increase in the number of erroneous responses (Bryck & Mayr, 2005; replications of Baddeley et al., 2001; Emerson & Miyake, 2003; Saeki & Saito, 2004; Saeki, Saito, & Kawaguchi, 2006). However, as noted by Baddeley et al. (2001), when a single task is performed (e.g. addition of 5 to successive numbers on a list), articulatory suppression does not significantly

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impact performance. Such vocalisations mostly influence responses when having to maintain multiple response configurations and/or sequential response patterns (i.e. during task-switching paradigms) (Bryck & Mayr, 2005). Therefore, there is a general consensus that verbal strategies are used to aid performance whenever a high level of competition between tasks is expected. Their specific role may still depend on the nature of the actions, with verbal strategies being associated with planning, sequencing, action control, motor functions and imagery, and temporal processing (Ullman, 2006).

1.1. The role of verbal strategies in task-switching designs

Most studies evaluating the impact of vocalisations in task-switching performance have used the list design. Here participants repeat each task individually in separate pure blocks of trials (AAA… and BBB…), and a mixed block where a switch is required on each trial (ABAB…). Performance is clearly better in the pure blocks than in the mixed blocks (Emerson & Miyake, 2003; Saeki & Saito, 2004; Saeki et al., 2006). This deterioration in performance between the pure and mixed blocks, despite being based on identical task repetitions, reflects the additional memory load or computations needed when handling potential switches in the mixed block. The list design has produced an enlightening series of studies characterising how articulatory suppression can impede performance in the mixed block. For example, we now know that this form of switching cost is affected by articulatory suppression with endogenous cues (Bryck & Mayr, 2005; Emerson & Miyake, 2003; Saeki & Saito, 2004), and with cues requiring greater levels of decoding (Miyake, Emerson, Padilla, & Ahn, 2004; Saeki & Saito, 2009). Interestingly, it is not influenced by variables commonly affecting trial-by trial performance, such as the interval between the cue and the target (Goschke, 2000; Saeki et al., 2006). Instead, its influence is greatest when manipulating variables that affect the entire block (or list), for example, when the switches are unpredictable as in the case of a random cuing paradigm (Miyake et al., 2004; Saeki & Saito, 2009).

Despite the list design providing a valid measure of executive control, it nevertheless comprises at least two different sources of costs, namely the mixing and the switch cost. One way to illustrate these two components is by including repeat trials in the mixed block. Although the original list paradigm traditionally avoids the inclusion of repetitions in the mixed block, this is central to other paradigms, for example the alternating runs design (Rogers & Monsell, 1995), where both repeat and switch trials are combined within the mixed block (AABBAA…). With this new strategy, both repeat and switch trials are measured under the same context with similar requirements of monitoring and memory load (Spector & Biederman, 1976). This new measure of switch cost reflects transient adjustments between task configurations from trial to trial (Rogers & Monsell, 1995). With this type of strategy, results have failed to demonstrate any contribution of verbalisations to switch costs (alternating runs, Bryck & Mayr, 2005; random runs, Saeki & Saito, 2009). Therefore, any verbal contribution to cognitive control must be found upon processes that affect the list design exclusively.

Saeki and Saito (2009) applied a modified version of the list design, a random cuing paradigm, (also including a pure and a mixed block), but allowing task repetitions in the mixed block. With this procedure it is possible to dissociate processes involved in trial-by-trial transient adjustments (differences between repeat and switch trials *within* the mixed block, or switch cost), from more strategic control mechanisms affecting performance in the pure and mixed blocks separately. If we compare the repeat trials in the pure block with those in the mixed block, the latter are usually slower, in what has been termed the mixing cost (Braver, Reynolds, & Donaldson, 2003; Los, 1996). With this modified list design, Saeki and Saito (2009) confirmed that articulatory suppression increased the mixing costs, whilst leaving switch costs unaffected. These results further support the idea that verbalisations play a role in sustaining more than one active task in working memory (Bryck & Mayr, 2005; Saeki & Saito, 2009), as opposed to facilitating switches to a new task (Rubinstein, Meyer, & Evans, 2001). This illustrates the need to specifically measure mixing costs separated from switch costs when addressing this issue (Emerson & Miyake, 2003; Kray, Eber, & Karbach, 2008; Marí-Beffa et al., in press. See, Monsell, 2003; Vandierendonck, Liefooghe, & Verbruggen, 2010 for recent reviews on other task-switching paradigms).

1.2. The connection between mixing and switch costs

An additional reason for studying mixing costs separated from switch costs is that the pure estimation of the latter can become contaminated by variations in the size of the former. This issue, previously alluded to by others (Rubin & Meiran, 2005; Ruthruff, Remington, & Johnston, 2001; Sohn & Anderson, 2001) mostly refers to the *processing dependency* between these two indexes[1] in which high levels of mixing cost can induce a reduction in switch costs without reflecting an improved switching performance.

Indeed, the usual interpretation of the switch cost is that any changes in this effect reflect differences in the ability to switch, not in the ability to repeat; hence the repeat trials act as a control. However, variations in the mixing cost may affect these repeat trials. Clearly, if we suspect variations in the levels of mixing cost, the mixed repeat trials cannot be considered as controls for switch, but experimental conditions for the mixing cost. For example, consider an extreme case of a participant that is incapable of maintaining the sequence and task order of trials during the mixed block. This lack of anticipation will make every trial unexpected and treated equally. In this context, it is possible that repeat and switch trials become highly similar, resulting in a minimum switch cost that cannot be interpreted as exceptionally good switching performance, but poor execution on repetition trials. For all these reasons, we will mainly focus on the influence of verbalisations upon variables affecting block performance, better measured by the mixing costs (see Marí-Beffa et al., in press, for a similar approach).

1.3. Verbalisation as a booster of cognitive control

Most previous studies investigating verbalisations with goal-directed behaviours have done so by determining the detrimental impact of articulatory suppression on task performance. Clearly this approach demonstrates how task monitoring can be achieved without verbalisations, or by severely impeding them. Few studies have attempted to directly investigate how or why verbalisations can *aid* performance. The articulatory suppression strategy can provide a good model to study the role of non-verbal working memory systems in task control, since it removes any potential contamination of the articulatory loop (Ullman, 2006). However, it cannot be used to understand how verbalisations can directly assist performance. The only condition where these verbalisations are often indirectly inferred is silent reading. Declared as a control condition, the internal nature of such verbalisations makes it impossible to be assessed. Our position is that we need to involve verbalisations directly to understand how they assist in task monitoring and performance. In this sense, only a few studies have investigated the benefits of verbalising task-relevant words, finding evidence of facilitation in comparison to articulatory suppression (Goschke, 2000; Kray, Eber, & Lindenberger, 2004; Kray et al., 2008; Miyake et al., 2004). From these, only Kray et al. (2008, 2004) and Miyake et al. (2004) included a silent reading condition, which allows assessment of whether the pattern observed corresponds to costs from the articulatory suppression condition, or from benefits associated

[1] We would also like to raise the obvious *statistical dependency* between mixing and switch costs. Both indexes are calculated using the same mixed repeat trials but with different roles: as an experimental condition for the mixing cost and a control for the switch cost. Any effect of mixing cost will induce changes in the very condition upon which the switch cost is based.

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to relevant outward verbalisations. These issues will be central in our research.

The positive influence of verbalisations on task switching can be illustrated by the fact that, even with concurrent irrelevant verbalisations, participants are still very capable of performing the tasks. This is important when considering the use of relevant inner or outer speech; it is not imperative that we use it. When used, it is performed in what could be described as a 'boosting' capacity — providing an enhancement of our capabilities. As such, the use of the phonological loop, with either inner speech or relevant verbalisations, assists in providing a verbal representation, or verbal label, of the task to be performed (Kirkham, Cruess, & Diamond, 2003; Kray et al., 2008; Müller, Zelazo, Hood, Leone, & Rohrer, 2004). However, as this use of the phonological loop is not mandatory, we have no guarantees that the participant necessarily uses it in the silent condition. Additionally, the frequency with which this strategy is used may depend on the task demands, becoming minimal when the cue is external and non-verbal (Emerson & Miyake, 2003; Miyake et al., 2004; Saeki & Saito, 2004, 2009), or when switches are predictable (Emerson & Miyake, 2003; Saeki & Saito, 2004; Saeki et al., 2006).

In the forthcoming studies we combine both the list and alternating runs designs to produce three trial formats: pure block repeats, mixed block repeats, and mixed block switches. The difference between pure and mixed block repeat trials (mixing cost) provides an index of the ease of sequencing and task order control, whilst the difference between the mixed block repeat and switch trials (switch cost) is used here to measure task rule implementation. To study the impact of verbalisations we used words as external cues, where three tasks are defined: Articulatory Suppression, Silent Reading, and Reading Aloud. The inclusion of Articulatory Suppression highlights the interference generated by irrelevant vocalisations on task control. The difference between Silent Reading and Reading Aloud allows evaluation of potential boosting benefits of external verbalisations.

2. Experiment one

This experiment evaluates the detrimental effect of articulatory suppression on task switching capabilities. In addition, we measure the potential benefits of engaging in relevant articulations by reading aloud the instructional cue. These two conditions are compared against silent reading, serving as an intermediate control. In this study, all instructional cues are explicit and exogenous, in a highly predictive sequence of trials with long cue-target intervals. These conditions isolate the use of verbal-strategies, minimising the contamination of concurrent memory-based strategies that could be elicited when engaging in more demanding and/or endogenous task requirements. Note that in this experiment we use a conservative approach — we include conditions that traditionally have failed to demonstrate the benefit of verbalisations on performance. To promote the use of articulation strategies we use task-relevant words as explicit task cues. The use of these words removes the requirement of translation, as would be required with less transparent task cues, yet still capitalises upon the integration of the phonological loop to decode the words into an inner-speech form (Gathercole & Baddeley, 1993). This will ensure that participants use articulation strategies to their fullest extent, rather than having to labour processes directed towards decoding the task cue prior to initialising the correct task set.

2.1. Method

2.1.1. Participants

24 undergraduate students of Bangor University were remunerated with course credits for their participation. All participants were required to have normal, or corrected-to-normal vision, and speak English as their first language.

2.1.2. Stimuli and apparatus

The experiment was displayed on a 19 in CRT monitor, and performed on a PC with a VGA card using E-Prime 1.1 (PST Software) computer software. Participants sat 60 cm from the display. The stimuli consisted of 2 shapes (square and circle) shaded in 2 possible colours (blue and red). The square was 2.6° high and 2.6° wide. The circle measured 2.6° in diameter. The colours of the stimuli were red (R:255, G:0, B:0) and blue (R:0, G:0, B:255). Each trial presentation consisted of a single stimulus being displayed in the centre of the screen on a white background. Prior to the stimulus display, a task cue was displayed in the centre of the screen. The task cue read 'BLUE/RED' (4.9° wide and 0.8° high), or 'SQUARE/CIRCLE' (7.3° wide and 0.8° high) in Courier New font. The response keys for the experiment were the letters C and N on a standard QWERTY keyboard.

2.1.3. Design and procedure

Each trial began with a task cue displayed in the centre of the screen for 1000 ms, followed by a 500 ms blank-screen interval. The stimulus was then displayed until response, followed by a 150 ms blank-screen interval, accompanied with a buzzer tone if an incorrect response was given. Three blocks of trials were performed: two pure repeat blocks of 40 trials each, one for colour and one for shape, and one mixed block of 160 trials in an alternating runs sequence. As a result, in the mixed block there were 80 repeat trials (40 colour and 40 shape), and 80 switch trials (also equally split). Mixing costs were calculated by computing the average response time of the repeat trials in the mixed block minus the average response time of the repeat trials in the pure blocks. Switch costs were calculated as the difference between the average response times of the switch and repeat trials in the mixed block.

Participants performed all trial blocks under three counterbalanced conditions: Silent Reading (of the task cue), Reading Aloud (of the task cue) and Articulatory Suppression. The experimenter was in the room during the experiment to ensure participants performed the task. In the Silent Reading condition participants performed the task in silence. During Reading Aloud, participants read aloud each task cue (when displayed) at a "standard conversational level". During the Articulatory Suppression condition participants stated aloud the word "blah" at a rate of approximately 2 Hz (Brown & Marsden, 1991; Saeki & Saito, 2004), also at the specified volume. Standardised instructions were presented on screen. Participants were instructed that they were to respond to stimuli according to a task-cue that would be presented. The task-cue would state Blue/Red or Square/Circle. In the event of Blue/Red appearing on-screen participants should respond to the forthcoming stimuli, pressing C if it was blue and N if it was red. Alternatively, if Square/Circle appeared on-screen, they should respond by pressing C if it was a square and N if it was a circle. They were informed that they should ignore the irrelevant property and only respond to the task-cue prompted characteristic. Participants were also asked to respond as quickly as possible, but to ensure good accuracy.

Participants were made aware that initially there would be two pure blocks of trials where the secondary property would not be required. After the two pure blocks, participants were informed that both task sets "would now be mixed together", and that they "will be performing the paradigm in an AABBAA format, for example Colour-Colour-Shape-Shape-Colour-Colour and this will require you [them] to remember both rules throughout the block".

Participants were tested individually and completed all conditions in a single session, taking approximately 45 min.

2.2. Results

All incorrect responses and those immediately following ($n+1$) were removed — any incorrect response would affect the alternating runs sequence. Any responses that were greater than 3 SD above the mean of each individual participant were also removed prior to reaction time data analysis (additional 1.6% removed). The following percentages of trials were removed in total: Reading Aloud — 11.7%; Silent — 8.7%; Articulatory Suppression — 16.1%.

2.2.1. Reaction times

Averages of trimmed RTs per participant were analysed through a three-way repeated measures ANOVA for the variables, Task (Reading Aloud, Silent Reading, Articulatory Suppression), and Trials (Pure Repeat, Mixed Repeat, Mixed Switch). Analyses using an additional basis of congruency (to account for the bivalent stimuli) were performed but did not highlight any significant interaction with Task [$F<1$]. Therefore these measures were collapsed and not included within the final analysis.

Overall differences across Task were demonstrated [$F(2,46)=18.37$, $p<0.001$, partial $\eta^2=0.44$]. Reading Aloud was significantly faster than both Silent Reading by 63 ms [$t(23)=3.85$, $p=0.001$], and Articulatory Suppression by 132 ms [$t(23)=5.19$, $p<0.001$]. Silent Reading was also significantly faster than Articulatory Suppression by 68 ms [$t(23)=3.04$, $p=0.006$]. There were also substantial differences across the Trials [$F(2,46)=48.24$, $p<0.001$, partial $\eta^2=0.68$], reflecting 55 ms of mixing cost [$t(23)=4.66$, $p<0.001$], and 65 ms of switch cost [$t(23)=8.14$, $p<0.001$].

A significant interaction was found across both Task and Trials, demonstrating that the RT of Trials was influenced by the Task [$F(4,92)=3.31$, $p=0.014$, partial $\eta^2=0.13$]. Therefore, further analyses were conducted on the mixing and switch costs separately.

Condition	Pure repeat	Mixed repeat	Mixed switch	Mix cost	Switch cost
Silent	454	514	592	60 ‡	78‡
	[17.34]	[23.34]	[31.33]	*0.4*	*2.5*
	96.8	*96.4*	*93.9*		
Art. Supp	518	594	653	76 ‡	59‡
	[25.31]	[33.42]	[38.63]	*2.0*	*4.1*
	94.3	*92.3*	*88.2*		
Reading Aloud	417	447	506	30 †	59‡
	[13.16]	[16.99]	[19.97]	*0*	*1.1*
	95.2	*95.2*	*92.6*		

RT (ms), [standard error]//†<0.01; ‡<0.001.
Italics = % of accurate responses (also includes accuracy costs in applicable columns).

The size of the mixing cost changed dependent on the Task [$F(2,46)=3.56$, $p=0.036$, partial $\eta^2=0.13$]. Analyses stated that Reading Aloud produced significant benefits in mixing costs compared to Articulatory Suppression [$F(1,23)=5.68$, $p=0.026$, partial $\eta^2=0.19$], and to Silent Reading [$F(1,23)=5.19$, $p=0.032$, partial $\eta^2=0.18$]. There was no difference between Silent Reading and Articulatory Suppression [$F<1$].

The size of the switch cost did not change significantly depending upon the Task [$F(2,46)=1.64$, $p=0.20$, partial $\eta^2=0.067$].

2.2.2. Accuracy

Analyses of overall accuracy indicated significant differences across Task [$F(2.46)=18.50$, $p<0.001$, partial $\eta^2=0.45$]. Silent Reading produced 95.7% accurate responses, 1.4% greater than Reading Aloud [$t(23)=2.50$, $p=0.020$], and 4.1% greater than Articulatory Suppression [$t(23)=5.66$, $p<0.001$]. Reading Aloud produced 2.7% more accurate responses than Articulatory Suppression [$t(23)=3.55$, $p=0.002$].

Significant differences were obtained across accuracy for Trial also [$F2,46)=27.64$, $p<0.001$, partial $\eta^2=0.54$]. Pure block repeat trials averaged an accuracy of 95.4%, whilst mixed block repeat trials averaged 94.6%. The mixing cost of <1% was not significant. Mixed block switch trials obtained an accuracy of 91.6%, resulting in a switch cost of 3% [$t(23)=5.74$, $p<0.001$].

The interaction between Task and Trial did not reach significance [$F(4,92)=2.46$, $p>0.05$, partial $\eta^2=0.097$].

2.3. Discussion

This experiment was designed to evaluate whether relevant verbalisations could aid performance in goal-directed behaviours. It was assumed that the silent condition, normally used to evaluate the contribution of sub-vocal rehearsal strategies, might not be stringent enough to guarantee the use of this form of (inner) verbalisation. Whether, or how often, participants use inner speech in this manner cannot be quantified; it is also uncertain whether this strategy varies across individuals, or across trials. To compensate for this, participants read aloud the instructional cue displayed on-screen. The application of this overt verbalisation resulted in significantly faster overall responses, and crucially a significantly reduced mixing cost, and hence interaction, against all other conditions, including Silent Reading. From these present results it could be considered that the application of overt relevant verbalisations provides assistance and facilitation to the sequential task-order demands of the paradigm that simply cannot be supplied under either Silent Reading or Articulatory Suppression. In this respect it is likely that processing dependency is a crucial factor, allowing this facilitation of performance. As a result, participants are aware of whether the upcoming trial is a repeat, thus ensuring speeded responses and a significantly smaller mixing cost.

3. Experiment two

Results from Experiment 1 showed that Articulatory Suppression resulted in significantly larger RTs than either of the other tasks. Additionally, the nature of the study is to investigate potential facilitation of goal-directed behaviours — the performance of Articulatory Suppression, although enlightening, is not used to investigate such traits.

With Reading Aloud producing significant RT benefits in comparison to Silent Reading, despite sharing similar processes prior to the evocation of verbalisations, theories as to why this may occur must be investigated. Although participant hearing levels were not measured, there is little doubt that when we verbalise we hear ourselves speak. Therefore it may be possible that any benefits obtained from reading aloud may result from a form of dual-encoding – input from both visual and auditory factors – rather than from the verbalisation itself. In this current experiment we implement a task where an auditory cue was presented using headphones. This condition replaced Articulatory Suppression as no further information could be gained from its inclusion.

3.1. Method

3.1.1. Participants

In this experiment, a new group of 28 undergraduate students of Bangor University were recruited and remunerated with course credits.

3.1.2. Stimuli and apparatus

All stimuli and materials were identical to those in Experiment 1. In addition, auditory elements were generated using the Apple Macintosh VoiceOver program to create vocalisations of the task cues ("Blue Red" and "Square Circle"). These were recorded and normalised to −1 dB. During testing, all audio was presented at a comfortable level using headphones. The headphones were worn throughout all tasks and blocks of trials to provide consistency, and were also used to present the error tone.

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3.1.3. Design and procedure

The task conditions were Silent, Silent with Auditory Input (Audio), and Reading Aloud. These were performed using the same procedure and design of Experiment 1. In the Audio condition, participants performed the task in silence, but the task cues presented onscreen were concurrently presented aurally through headphones.

3.2. Results

Using an identical procedure to Experiment 1, all incorrect responses and those immediately following $(n+1)$ were removed. Any responses that were greater than 3 SD above the mean of each individual participant were also removed prior to reaction time data analysis (additional 1.6%). The following percentages of trials were removed in total: Silent — 12.8%; Audio — 11.7%; Reading Aloud — 12.5%. Three participants were removed prior to analysis as investigations of boxplots indicated these participants as outliers.

3.2.1. Reaction times

Averages of trimmed RTs per participant were analysed through a three-way repeated measures ANOVA for the variables, Task (Silent Reading, Audio, Reading Aloud), and Trials (Pure Repeat, Mixed Repeat, Mixed Switch). As with Experiment 1, analyses using an additional basis of congruency were performed, but did not highlight any significant interaction with Task [$F<1$]. Therefore these measures were collapsed and not included within the final analysis.

Overall differences between Tasks were found [$F(2,48)=5.01$, $p=0.011$, partial $\eta^2=0.17$]. Audio was significantly faster than Silent Reading by 21 ms [$t(24)=3.15$, $p=0.004$]. Reading Aloud was also significantly faster than Silent Reading by 19 ms [$t(24)=2.32$, $p=0.029$]. There was no significant difference between the Audio and Reading Aloud tasks [$t(24)=0.29$, $p=0.78$]. There were also substantial differences across the Trials [$F(2,48)=61.12$, $p<0.001$, partial $\eta^2=0.72$], reflecting 35 ms of mixing cost [$t(24)=4.94$, $p<0.001$], and 53 ms of switch cost [$t(24)=8.94$, $p<0.001$].

A significant interaction was found between Task and Trials, demonstrating that the RT of Trials was influenced by the Task [$F(4,96)=3.36$, $p=0.013$, partial $\eta^2=0.12$]. Further analyses were conducted to determine the mixing and switch costs.

Condition	Pure repeat	Mixed repeat	Mixed switch	Mix cost	Switch cost
Silent	411	463	497	52 ‡	34 ‡
	[11.36]	[16.32]	[16.58]	*0.7*	*2.8*
	96.1	*95.4*	*92.6*		
Audio	397	421	490	24 §	69 ‡
	[10.88]	[13.86]	[18.19]	*1.1*	*1.9*
	95.8	*94.7*	*92.8*		
Reading Aloud	401	429	484	28 †	55 ‡
	[12.37]	[15.73]	[18.75]	*+1.2*	*4.2*
	94.6	*95.8*	*91.6*		

RT (ms), [standard error]//§ = 0.020; † < 0.01; ‡ < 0.001;
Italics = % of accurate responses (also includes accuracy costs in applicable columns).

The size of the mixing cost changed dependent on the Task [$F(2,48)=4.50$, $p=0.016$, partial $\eta^2=0.16$]. Analyses stated that Audio produced significant benefits in mixing costs compared to Silent Reading [$F(1,24)=8.16$, $p=0.009$, partial $\eta^2=0.25$]. Reading Aloud also produced significant benefits to Silent Reading [$F(1,24)=4.31$, $p=0.049$, partial $\eta^2=0.15$]. There was no influence on mixing cost between Audio and Reading Aloud [$F(1,24)=0.25$, $p=0.62$, partial $\eta^2=0.010$].

The size of the switch cost also changed significantly depending upon the Task [$F(2,48)=7.45$, $p=0.002$, partial $\eta^2=0.24$]. Both Audio and Reading Aloud showed significant impact on switch costs compared to Silent Reading [$F(1,24)=13.86$, $p=0.001$, partial $\eta^2=0.37$ and $F(1,24)=5.16$, $p=0.032$, partial $\eta^2=0.18$ respectively]. There was no influence on switch cost between Audio and Reading Aloud [$F(1,24)=2.63$, $p=0.12$, partial $\eta^2=0.099$].

We further explored the source of the interaction between switch cost and task by directly comparing task influences on each of the trial forms. Importantly, the type of task did not influence the switch trials [$F(2,48)=0.75$, $p=0.48$, partial $\eta^2=0.030$] and instead, it produced maximum impact on the repeat trials [$F(2,48)=12.15$, $p<0.001$]. During these trials the silent condition produced significantly slower reaction times than both Reading Aloud [$t(24)=3.18$, $p=0.004$], and Audio [$t(24)=4.81$, $p<0.001$]. There were no differences between the Reading Aloud and Audio tasks in the repeat trials [$t(24)=1.10$, $p=0.28$].

3.2.2. Accuracy

Analyses of overall accuracy indicated no significant differences across Task [$F(2,48)=0.84$, $p=0.44$, partial $\eta^2=0.034$]. Significant differences were obtained across accuracy for Trial forms [$F(2,48)=16.64$, $p<0.001$, partial $\eta^2=0.41$]. Pure block repeat trials averaged an accuracy of 95.5%, whilst mixed block repeat trials averaged 95.3%. The mixing cost of <1% was not significant [$t(24)=0.33$, $p=0.74$]. Mixed block switch trials obtained an accuracy of 92.3%, resulting in a switch cost of 3% [$t(24)=4.56$, $p<0.001$]. There was no significant interaction between Task and Trial [$F(4,96)=2.01$, $p=0.099$, partial $\eta^2=0.077$].

3.3. Discussion

Following on from the results of Experiment 1, it was unclear whether the results obtained for the Reading Aloud condition were a result of the articulation given by the participant, or as a result of the participant hearing themselves state aloud the task cue. A fresh condition was implemented, whereby audio task cues were presented in place of the participant reading them aloud. This new condition replaced the Articulatory Suppression condition of Experiment 1.

Interestingly, both Reading Aloud and Audio conditions demonstrated significant benefits (through reduced mixing costs) compared to Silent Reading. Furthermore, there were no significant interactions obtained between these two conditions.

Additionally, there were highly similar response times obtained for the pure repeat and switch trials across all three conditions. Yet despite these similarities, significant effects of mixing cost (and resultantly, switch costs) are obtained between the Silent Reading condition and both Reading Aloud and Audio conditions independently.

Of special note is the pattern of mixing costs/switch costs emerging from the audio condition where a small mixing cost (24 ms) corresponds with a significantly larger switch cost (69 ms). As mentioned earlier, it is the repeat trials in the mixed block that seem to be responsible for both effects. Indeed, the switch cost can be interpreted both as the difficulty to switch (task preparation) and ease of repetitions (repetition benefits), becoming two dissociable components (Allport, Styles, & Hsieh, 1994; Ruthruff et al., 2001; Sohn & Anderson, 2001). It is likely that the audio condition specifically induced repetition benefits in the mixed block without influencing the switch trials to the same extent. Sohn and Anderson (2001) found that the preparation interval improved RTs selectively in the switch trials. Foreknowledge of whether the upcoming trial was a switch or a repeat resulted in marked benefits; mostly in the repeat trials (see Experiment 1, Fig. 3 in Sohn & Anderson (2001)). The influence of foreknowledge on repeat mixed trials is in line with previous theoretical explanations for mixing costs. As described by Bryck and Mayr (2005), the mixing cost reflects the inability to keep the sequence of trials in sustained attention. Our data supports that auditory instructions aid the maintenance of trial sequences by providing foreknowledge of what is coming next and that its biggest influence is observed in the repeat mixed trials.

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To sum up, reading aloud the task cue, or indeed hearing the task cue, appears to facilitate a prompt response to mixed repeat trials, indicating that task-order sequences are being maintained with the use of these processes.

4. General discussion

In these experiments the role of verbal and auditory representations of task cues on goal-directed behaviours was explored. An alternating runs paradigm (Rogers & Monsell, 1995), coupled with elements of the list paradigm (single-task repeat trials), was used for all experiments. In all variations and conditions, participants responded to either the colour or shape of bivalent stimuli in accordance with an instructional task cue.

Experiment 1 investigated whether relevant verbalisations could aid performance, in comparison to articulatory suppression. As expected, the slowest and most error prone responses were in the Articulatory Suppression condition (Baddeley et al., 2001; Bryck & Mayr, 2005; Emerson & Miyake, 2003; Saeki & Saito, 2004; Saeki et al., 2006). The fastest reaction time (RT) performance was produced when reading aloud the task cue. Despite substantial mixing cost effects in all three tasks, Reading Aloud produced a significantly smaller mixing cost than both Articulatory Suppression and crucially, Silent Reading.

Experiment 2 provided the inclusion of an Audio condition, designed to specifically assess whether the benefits obtained by reading aloud the task cue in Experiment 1 could be due to the auditory feedback of this process. As in Experiment 1, Reading Aloud produced faster overall responses than Silent Reading. This result was also obtained in the Audio condition — though there was no significant difference between Reading Aloud and Audio. Decisively, as in Experiment 1, mixing costs were present in all three tasks, but Silent Reading produced a significantly larger mixing cost compared to both Reading Aloud and Audio. There was no difference in the mixing costs obtained from the Reading Aloud and Audio tasks.

4.1. Mixing-cost findings

In the introduction, theoretical viewpoints were outlined that could explain a connection between the mixing cost and the switch cost, leading from processing and statistical dependencies. We believe that the experiments presented here justify the discussion and future research of this connection.

Although both experiments show clear signs of mixing cost effects, we believe that Experiment 2 shows the most interesting aspects of the current research. There is little disputing the similarities between both the methods employed (Silent, Reading Aloud, and Audio), and more specifically the results obtained. All are common, everyday protocols and all are focussed upon providing improved performance — completing a task in silence, with self-direction, or indeed with auditory directions being provided. Since all conditions are similar, and involve no irrelevant verbalisations (unlike Experiment 1), it is likely that this is why such similar results have been obtained for both the pure repeat and switch trials. Accordingly, it can be concluded that, within the confines of this experiment, both floor and ceiling reaction times (respectively) have been reached for each condition.[2] In spite of this, there remains a significant effect of mixing cost between the conditions; an effect obtained because of the significantly slower mixed-repeat trial RTs of the Silent Reading condition. The slowing of these RTs in turn results in an effect upon the switch cost since this inflation has not occurred with the remaining conditions (e.g. Reading Aloud and Audio). In this sense statistical dependency is present; where mixed-repeat trial RTs are swift a large increase is required to reach the ceiling level of switch trials (e.g. a large switch cost), however where these RTs are slower, a smaller increase is required, resulting in a smaller switch cost. The speeded responses obtained for the mixed-repeat trials for both Reading Aloud and Audio ensures that a large switch cost is found. However, because the mixed-repeat trials of the Silent Reading condition were elevated in comparison, the switch cost for this condition is much smaller, resulting in this significant effect. This is clearly not a result of an improved ability to switch in the Silent Reading condition, but instead a result of the diminished ability to perform repeat trials.

For a switch cost interaction to be fully justified all RT responses towards the mixed-repeat trials should be comparable, providing a level base from which switch costs can be measured. Due to the significant interaction of mixing cost in this instance, this is not an acceptable basis from which to determine such measures. In this sense, these results could be attributed towards a processing dependency factor. Yet, performance during Silent Reading does not deteriorate to the point where mixed-repeat and switch trial RTs are comparable. However, there is still undoubtedly a slowing in responses, which can be attributed to a diminished ability to maintain task-order sequences as competently as with the other conditions.

It is important to highlight that in comparisons between Experiments 1 and 2, the Silent condition seems to change particularly in the switch costs, with no substantial difference in the mixing costs. This effect appears solely in the Silent condition, with Reading Aloud producing near identical costs in both experiments. Considering that all conditions are manipulated within subject, this makes us question whether the impact of articulatory suppression may have an influence on how the silent reading task is carried out. Although lacking the power needed for these analyses, our data indeed suggests that participants who performed the silent condition after articulatory suppression displayed larger switch costs than those that followed reading aloud. This leaves open the possibility that individual strategies may have a direct influence on the switch cost.

However, this is difficult to be assessed in the silent condition since there is no explicit strategy required of the participant (i.e. reading aloud or articulatory suppression). Reading aloud, on the contrary, exhibits stable costs across both experiments. These differences further support our belief that a silent condition is not a suitable control when studying the contribution of language on cognitive control. Instead, all conditions should utilise explicit linguistic actions that can be monitored. It should be stated that we do not believe there is a general language contribution, rather that each process exhibits its own peculiarities. For instance whether the cue is presented visually or through auditory means may provide a different influence upon response capabilities; this will need to be studied further. In any case, our results demonstrate that in order to understand any contribution of language, we need to make a decision about precisely which aspect of language to study. Neither articulatory suppression nor silent reading (the two tasks most commonly used in this form of study) serves this purpose.

4.2. The impact of verbal and auditory cues on mixing costs

Few previous studies have used an alternating runs design combined with a single task pure block (Kray et al., 2008). Yet without the mixed repeat trials (as also found with random cuing designs) it is not possible to measure mixing costs. The pure block provides measures of single-task performance, and of repeated and consistent practice with the same stimulus–response (S-R) mappings. One task-set is used in each pure block, meaning there is little interference from competing task sets. When the same task is repeated within an alternating runs block, practice becomes inconsistent, due to interference and competition from other task sets.

[2] With this range of participants in particular — it is highly likely that with a different range of participants, e.g. older adults, children, etc. that the results will be greatly different with respect to the ceiling and floor measures of responses. We thank an anonymous reviewer for highlighting this.

Experiment 1 confirmed that articulatory suppression makes it harder to manage conflict between tasks in the mixed block. It is often stated that articulatory suppression has a negative impact on performance with regard to switch costs (Baddeley et al., 2001; Emerson & Miyake, 2003; Goschke, 2000; Saeki & Saito, 2004; Saeki et al., 2006). The measure of switch cost under debate here has been obtained from the list paradigm, where mixing costs and switch costs are confounded. The present study instead highlights that articulatory suppression exerts a very strong negative influence on the mixing cost, but not on the switch cost.

The articulatory suppression task only provides an indirect means to address the role of verbal representations on sustained goal-directed attention. Furthermore, the Silent task does not provide a compelling verbal condition to compare against articulatory suppression. As evidenced from our studies, mixing costs are reduced when task cues are read aloud compared to silent reading. Since these relevant articulations assist in the performance of a task, it is unclear why participants achieved the results they did during silent reading, as sub-vocal articulation was always an option. After the experiment, participants were asked if they had engaged in inner-speech during the Silent Reading condition; all participants responded unanimously that this was the case (see also Emerson & Miyake, 2003). It is possible that although this approach may have been used, it could have been inconsistent, as we have no direct means of confirming this.

As for the benefits obtained from reading aloud the task cue, we must not ignore that overt verbalisations require additional demands compared to silently reading them. Basic reading processes should be common in both conditions with the differences occurring mostly during the final stages, where the *additional* verbalisation takes place only for reading aloud. If anything, we expected the extra cognitive demands occurring during reading aloud to deteriorate performance. In spite of this, the participants responded faster than when they were silent.

Experiment 2 showed that the *sound output from overt verbalisations, and thus input for auditory processing*, might be responsible for the improved performance. In this study, comparable benefits (to those also found when reading aloud) were obtained through auditory presentation of the task cues. However we cannot be sure whether this auditory input and processing is exclusively responsible for the reduced mixing cost.

In principle, it could be that auditory input alone (obtained with both Reading Aloud and Audio) provides this benefit. Alternatively, it could be that both auditory and articulatory processes aid performance in the mixed block in conjunction, or as separate processes that do not interact with each other. Undoubtedly, our results demonstrate that different verbal mechanisms can boost performance during the mixed block. These benefits add to those observed in silent reading and seem to specifically target the mixing costs.

The mechanisms concerning how this works are a question of debate. One possibility is that verbalisations help reduce the interference of the irrelevant property in the mixed block. During the pure block, the irrelevant dimension is never attended to; therefore very little interference would emerge from incompatible trials. In the mixed block, however, both dimensions are relevant as they are mapped onto the two participating tasks. This increased interference in the mixed block may contribute to the mixing cost (Rubin & Meiran, 2005), and the use of verbalisations may assist in the correct task-relevant decoding of the stimuli. A clear prediction from this account is that the type of task would have a strong impact on incongruent trials, but not on the congruent ones. On the contrary, we found that an identical pattern to the one reported here was observed for the congruent trials, where interference was minimal. Indeed, congruency did not interact with any of the cue tasks. This result further supports the idea that verbal representations do not act on processes affecting individual trials, influencing instead the entire block.

An interesting possibility is that verbalisations aid sustained concentration on tasks during the mixed block, reducing the impact of boredom, fatigue or distraction.[3] Although our blocks were possibly not long enough to be sensitive to these influences (see, for example, two hour long testing sessions used in van der Linden, Frese, & Meijman, 2003, examining mental fatigue), we tested whether there was any difference between the first and second halves of the mixed blocks. We failed to observe any clear pattern to support this, although acknowledge that for this purpose longer blocks should be tested.

Finally, it is possible that verbal representations are critical in the maintenance of sequences of rules in working memory (Bryck & Mayr, 2005). This idea comes from paradigms that encourage endogenous control in conjunction with articulatory suppression, where participants need to remember the previous task in order to prepare for the next (Bryck & Mayr, 2005; Emerson & Miyake, 2003; Saeki & Saito, 2004). From this theoretical perspective, verbal working memory helps to maintain task sequences, allowing swifter responses in the mixed block. With our experiments, using a highly predictive alternating runs design with ample intervals for preparation[4] and unambiguous explicit cues, it could be argued that this reduces the working memory load as required for task sequence maintenance. However it does not remove it altogether. Often, where exogenous cues are used, they remain on-screen until a response is given (Bryck & Mayr, 2005; Miyake et al., 2004); this reduces the necessity for verbal working memory. As a result, articulatory suppression has little negative impact. By removing the task cues from the screen before the target appears makes the use of verbal working memory more likely, since this may facilitate the maintenance of the appropriate task response rule.

In addition, the word (task) cue may contribute to the activation of verbal articulatory code. There is already evidence that oral responses are activated to a greater extent than other forms of responses. For example, it has been demonstrated that Stroop interference is greater from words when responding orally, as opposed to pressing keys (e.g. Redding & Gerjets, 1977, see MacLeod, 1991, for a review). Our task cues benefit from the use of verbal strategies because, as words, they stimulate verbal articulatory processing. It is important to note that the use of these strategies can be seen as unnecessary, however, an additional boost of verbal or auditory processing of the task cue can clearly benefit performance.

Although very few previous studies have used such explicit and transparent cues, we believe that we have used this method to our advantage. Making the task as straightforward as possible enabled participants to engage from the very first trials, ensuring that they were not inadvertently fatigued, and that the results obtained were clear and pronounced. As previously detailed, it could be argued that explicit cues minimised the requirements for the preparation of task-set sequencing and reconfiguration. If indeed such cues negated the need for these preparatory processes our results would not have demonstrated the interactions between conditions that are present. The use of these cues primarily allows the preparation of reconfigurations to be more succinct and speeded, ensuring that the participants are capable of a more fluid sequencing process. Clearly this was not always the case; conditions with verbalisations permitted a greater

[3] We thank an anonymous referee for suggesting this possibility.

[4] Although RTs can be affected by the preparation time of a trial, particularly during Articulatory Suppression (Goschke, 2000; Miyake et al., 2004), this is not a major consideration here. Despite providing a 1500 ms preparation period for each trial, Articulatory Suppression still produces a slowed response. Although this period is quite extensive, working memory processes are required to ensure a correct response since the task cue is removed from the screen for 500 ms prior to the onset of the stimulus. This helps to ensure that the task cues are used to their fullest extent, *to facilitate task-order sequencing abilities,* rather than relying upon the task cue itself. Although the 1000 ms task cue presentation time may seem excessive, it is only enough for the concurrent reading aloud/audio information to be presented.

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level of cognitive control and task-order maintenance than those without.

In order to demonstrate that the results obtained are specifically related to the maintenance of sequential task rules (Bryck & Mayr, 2005), the use of an alternating runs design is imperative. Although other studies have made use of pure repeat trial blocks combined with paradigms requiring repeat trials in a mixed block (random cuing: Miyake et al., 2004), the alternating runs design is the only suitable paradigm for drawing conclusions of this nature. If the participant is oblivious to the format of the paradigm and upcoming trial (switch or repeat) then it is not possible to determine any such conclusions (e.g. as with the random cuing design). The maintenance of sequential task rules is only possible if a determinable sequence is used. Although we couple our explicit task cues with our predictable pattern of presentation, this only serves to reinforce the findings obtained. If our experimental conditions had produced no significant difference in mixing costs, particularly between the silently presented trials and those consisting of either verbal or auditory manipulations, then there would be no grounds for our conclusions. However, the case remains that despite the above acknowledgements of task simplicity, task-order maintenance appears to be facilitated by *additional* verbal instructions, as evidenced by the reduction in mixing cost.

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